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DESIGN CONSIDERATIONS OF RADOMES: A REVIEW

V. Mercy Soumya, S. Navaneetha and A. Nagarjun Reddy
Final Year B. Tech, Department of Mechanical Engineering,
Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad, India

J. Jagadesh Kumar
Associate Professor, Department of Mechanical Engineering,
Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad, India

ABSTRACT

The word Radome is a contraction of radar and dome. Radome is a structural enclosure above the Radar so as to protect the antennas from external environmental disturbances. There are several considerations in the design and fabrication of Radomes. Microwave or Radar antennas can be protected by a radome which is a structural, weatherproof enclosure. Radome is transparent to Radar or radio waves and protects the antenna surfaces from the environmental factors like wind, rain, ice, sand, ultraviolet rays, etc. and conceals antenna's electronic equipment from public view. Nearby personnel are protected from being struck by quickly-rotating antennas accidentally. The current review discusses about Radomes and tries to present their constructional details and design consideration in detail. The scope of the current review also includes discussion of applications, functions, frequent damages, maintenance issues and recent development trends of Radomes.

Key words: Dielectric Space Frame (DSF), Radome, Antenna, Signal, Fiberglass Reinforced Plastic (FRP).

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1. INTRODUCTION

The word Radome is a contraction of radar and dome. Microwave or Radar antennas can be protected by a radome which is a structural, weatherproof enclosure. Radomes are constructed of material that minimally attenuates the electromagnetic signal transmitted or received by the antenna. Radome is transparent to Radar or radio waves and protects the antenna surfaces from the environmental factors like wind, rain, ice, sand, ultraviolet rays, etc. and conceals antenna's electronic equipment from public view. Nearby personnel are protected from being struck by quickly-rotating antennas accidentally. Radomes can be constructed in several

shapes like spherical, geodesic, planar, etc.using various construction materials like fiberglass, PTFE-coated fabric, etc. depending upon the required application.

Radome is one of the important parts of Radar's mechanical construction. The Radome protects the radar against environmental disturbances. There could be some signal attenuation or signal losses introduced by the radome and this level of attenuation should be kept to the minimum. The strength of the radome is one of its important design considerations, but in the process of achieving better strength, the weight should not be increased just like that, as that has other serious consequences on the Radome structure. One more important consideration for a Radome design and selection is cost. The cost incurred in the design and fabrication of a Radome should be much less, when compared to that of the Radar that it is intended to protect. Other design considerations of Radome includethe topology, material, mechanical properties and effects of a radome on the transmitted or received signals. Topology or geometric shape plays a vital role in the design of a Radome.

The construction of a radome is a combined expertise of materials science, structures and electromagnetics, geodesic domes. Currently, there are four types of dielectric radomes. The four types identify themselves primarily by the radome wall construction. For adjacent panel assembly, the dielectric panel edges are reinforced into flanges. After assembly, the radome dielectric flanges form a framework establishing the general terminology Dielectric Space Frame (DSF).The four types of DSF Radome are as follows[1]:

- Thin Membrane: Adjacent panel flanges carry all the wind loads. Wall thickness is usually 0.040 inch or less.
- Solid Laminate:Wall thickness is typically 0.090 inch.
- 2-Layer Sandwich: A 2-Layer Sandwich wall radome is formed by adding a layer of foam to the inside thin membrane wall DSF radome.
- 3-Layer Sandwich: It is a composite foam core wall radome. Core thickness is chosen as ¼ wave length for the highest RF signal frequency.

2. RADOME APPLICATIONS

Radomes can be used to protect any of the following equipment [2].

- Military and Civil Radar
- Surveillance
- Telecommunications
- Weather Radar
- Coastal surveillance
- Satellite communications
- Microwave
- Broadcast equipment
- Military and Civil flight simulation

3. RADOME FUNCTIONS

- Radome protects the radar installation from the deteriorating effects of environment and extends the durability of antenna and other equipment.
- The overall performance of the antenna will be increased with the use of radome.

- FRP (Fiberglass Reinforced Plastic) radome helps to have overall economy and weight reduction.
- A Radome permits the airborne antenna to function with good efficiency under high head of the water over the submarine.

4. DESIGN CONSIDERATIONS

4.1. Construction and Materials

Reinforcements such as fiberglass, quartz, graphite, and Kevlar along with materials such as polyester, epoxies, and cyanate ester are used to make advanced composites and special products. Core materials such as honeycomb (fiberglass, aluminium and graphite) and foams (Polyisocyanate and thermoform able cores) are also used. Depending on the application, these parts are oven-cured at temperature up to 400^{o}F or in autoclaves, which require high-pressure cures at high temperatures. Other materials are also available for special applications. Regardless of the application, we can select the right combination of reinforcement and matrix to meet requirements [3].

4.2. Optimal Design for the Radome Wall Structure

Before designing a radome by calculating the transmission efficiency in an effective way, some hypotheses are made as follows:

- Plane wave solutions are used in mathematical descriptions of wave propagation in order to synthesis more complicated wave fronts. A plane wave is a mathematical but useful idealization because at large distances from sources and over regions of restricted size, curved wave fronts can be described approximately by plane wave functions.
- The theory of plane wave propagation through a plane dielectric sheet is used for radome design because a curved radome can be approximated as local plane. Thus, this paper studies propagation through flat sheets only. The flat sheet is a practically useful and instructive boundary valve problem, which demonstrates quantitatively how wave propagation depends on the dielectric constant and thickness of the sheet as well as the wave frequency, polarization and incident angle of the wave.
- A linearly polarized wave with the polarization either parallel or perpendicular to the plane of incidence is considered and the calculation methods for the complex valued transmission efficiency of a homogenous, isotropic, nonmagnetic and dielectric sheet are developed.

4.3. Calculation Model

Over the decades, numerous simulation methods for broadband electromagnetic wave penetration property have been developed, including the basic electromagnetic wave theory, finite elemental analysis, transmission line method, etc. For single layer structure, it is easy to calculate the wave transmission properties but for multilayer structure, such as A-sandwich (3 layers) and C-sandwich (5 layers), etc., the calculation becomes complicated and it is difficult to calculate the transmission efficiency directly when the layer number is greater than 5. F. Chen et. al. developed a new method named microwave equivalent network method to simplify the calculation for the graded porous structure [4].

4.4. Electromagnetic Optimal Design

The Radome will suffer ultra-high temperature (1500-2000 ^{o}C) when the missile flight speed is higher than 5 mach before hitting the target, which is a huge challenge for radome material. Silicon nitride (Si_3N_4) ceramic is the best candidate for high speed radome application because of its superior properties.

The defined frequencies are often used for active or half active self-direction missile system, while the broadband (1~18GHZ) wave transmission efficient is often used for passive self-direction missile application. The most commonly used and reported broadband radome wall structure includes A-Sandwich, C-Sandwich and multilayer. Functionally Graded Materials (FMS') have been developed early in the 1990's and are considered to be one of the best structures to relax the thermal stress between layers which are specially designed for ultra-high temperature application [4].

4.5. Design and Effective Parameters Extraction

The design of meta material-radome for a patch antenna operating in the UTMS band requires the entire determination of its electromagnetic characteristics around the operating frequency with well-defined properties. The composed multi-layered media should have an effective index of refraction near zero with low losses to not modify the antenna performances. In this study, the meta-material radome is made by aligning the layers of the square Split Ring Resonators "SSRs" alternately with layers of air. The SSR structure is printed on FR4 substrate with a thickness of h=0.8mm and a 35µm copper thickness for the metallic layers. Since the meta material-radome is a 3D periodic structure of Split Ring Resonators "SSRs", the effective permittivity and permeability of a metamaterial-slab are computed with An soft-HFSS software by using both the Perfect Electric Conductor (PEC) and Perfect Magnetic Conductor (PMC) boundaries. This method allows the microwave characterization of a semi-infinite effective homogenous slab with an infinite periodic array structure.

For a plane wave incident, normally on the homogenous slab of thickness d, we compute the effective permeability from the reflection (s_{11}) and the transmission (S_{22}) coefficients of the simulated structure. In our case the structure should be optimized to have the desired properties (negative permeability with low losses) at around the operating frequency of 2.17GHz [6].

4.6. Radome Flanges and Joints

The electromagnetic performance of a sandwich radome is made up of loss or scattering attributable to 1) the panel window area and 2) the panel flanges.

Loss and shift of phase due to the second factor (i.e., the panel flanges) can be nine times that of the panel window area. As a result, the flanges must be tuned or impedance-matched to the window area. There are two flange frameworks common to the radome industry. The first type is called a perpendicular joint. The second type is called a parallel lap joint.

The hardware for the perpendicular joint is internal to the radome. The parallel lap joint hardware punctures the radome surface and is both external and internal to the radome. Parallel lap joint hardware protrusions collect dirt and fungus and allow corrosion to attack metals exposed to the outside environment. From a framework shadow point of view, the perpendicular joint has a very narrow cross section. This contrasts significantly with the large lap joint cross section shadowing the dish reflector. Due to its smaller width, the perpendicular joint has a scattering width 8 times smaller than its parallel lap joint counterpart.

4.7. Hydrophobic Coatings

Nothing degrades radome performance more than a thin sheet of water. Water has very high dielectric constant and loss tangent at microwave frequencies. Non-hydrophobic surfaces cause water to stick to the radome, creating a thin film which serves as a shield to RF transmission, resulting in significant signal attenuation. Well-designed radomes feature a hydro-phobic surface that causes water to bead up and run off. Even in high rain conditions, a

radome with a hydrophobic surface has little additional attenuation. A surface is hydrophobic if the contact angle is greater than 90 degrees [2].

5. RADOME DAMAGE

The most common damage to radomes is holes in the structure caused by static discharge. These can be large holes that are readily apparent, or small pin holes that are almost imperceptible. Any hole, regardless of size, can cause major damage to a radome since moisture can enter the radome wall and cause internal delamination. If the moisture freezes, more serious damage may occur. If moisture collects, the radiation pattern will be distorted and the transmitted signals and return echoes seriously attenuated. Ram air through a hole can delaminate and break the inner surface of the radome and result in separation of the skins or faces of the material from the core, weakening the radome structure. Other types of damage are characterised as dents and scratches caused by impact with stones and birds and improper handling of the radome when it is removed for maintenance of the radar antenna. This type of damage is easily found by inspection.

6. MAINTENANCE

High performance radar radomes are very precisely constructed and sometimes the slightest change in their physical characteristics, such as excessive layers of paint, can adversely affect radar system performance. All repairs to radomes, no matter how minor, should return the radome to its original or properly altered condition, both electrically and structurally. The performance of proper maintenance to precision radomes requires special knowledge and techniques and the use of proper tools and materials. An improper minor repair can eventually lead to an expensive major repair. A radome having undergone major repairs should be tested to ascertain that its electrical properties have not been impaired. The testing of radomes requires test equipment that usually is found only in repair facilities specializing in radome maintenance. Even minor repairs may affect one or all of the following

- Transmissivity: The ability of a radome to pass radar energy through it.
- Reflection: The return or reflection of the outgoing radar energy from the radome back into the antenna and waveguide system.
- Diffraction: The bending of the radar energy as it passes through the radome.

These electrical properties, when altered by improper repair, may cause loss of signal, distortion and displacement of targets, and can clutter the display to obscure the target. Poor radome electrical performance can produce numerous problems which may appear to be symptoms of deficiencies in other units of the radar system. The following are examples of improper repair:

- Use of wrong materials – not compatible with original radome materials.
- Patches of different thickness.
- Poor fabrication techniques.
- Nonvoid-free patches.
- Repairs overlapping.
- Holes plugged with resin, screws, metal, wood, and plastic plugs.
- Cuts or cracks simply coated with resin.
- Tape (including electrical tape) over hole or crack and covered with resin.
- Oversize patches.

- Too much or too little resin.
- Exterior coatings – too many coats, too thick, uneven thickness – metallic base paints.
- Filled honeycomb cells.
- Repairs made without removing moisture or moisture contamination from inside of radome wall.
- Abrupt changes in cross-sectional areas.
- Patches projecting above outside contour lines.
- Improper cure.
- Wrong size cells or density of honeycomb.
- Excessive overlap in honeycomb joints.
- Poor bonding of skin to core.
- Gaps in honeycomb core.

7. RECENT TRENDS IN RADOMES

A new type of a radome based on SRRs metamaterials was designed, simulated and manufactured for a patch antenna operating in the UMTS band by Mohamed Latarch et. al (2010). It was a multi-layered radome composed of three FR4 layers of thickness 0.8 mm and permittivity 4.4 separated by two air-layers, with a 2-D 7 by 8 periodic matrixes of SRRs printed on each FR4 layer. The structure (antenna with radome) showed improved performances (+ 3.4 dBi for gain, + 2.9 dB for the directivity). It was proposed that the radome developed could be used for base-station antennas array placed on the buildings in order to protect them from their environment, improve their gain and reduces the side lobes of their radiation patterns [5].

O. Russo et. al.analyzed several radome materials and wall configurations in the special case of mobile applications (land, maritime and avionic) and the different mobile environments (maritime, aircraft, high speed trains and rubber wheeled vehicles) yielded very distinct radome requirements and require individual attention. Several candidate materials and layups were compared in terms of electro-mechanical performance by means of both theoretical and experimental evaluations [6].

G.A.E.Crone et. al. proposed that the performance of airborne antennas place comparable demands on the design of the enclosing radome to ensure minimal degradation of the antenna radiation pattern. The geometry of the radome, being largely determined by aerodynamic considerations, often leads to severe degradation of the electrical performance of any enclosed antenna. Rain erosion and heating of the radome surface also constrain the electrical design by limiting the choice of material and builds. The electromagnetic design and analysis of such radomes was discussed and the sources of degradation of the enclosed-antenna radiation pattern were presented. The design requirements with reference to the operational environment were also discussed [7].

M. Chandra Sekhar Reddy et. al. discussed about the design and development of dipoloop antenna radome. The radome is exposed to the environment where in it has to sustain the mechanical loads arising from wind loads and dynamic vibration levels. The dipoloop antenna radome is made of E-Glass fibers and epoxy resin. Static wind load, Eigen value, shock analysis and random vibration analysis were carried out using FEA (Finite Element Analysis) to investigate whether the radome withstands the wind loads and the dynamic vibration [8].

J. Diaz et. al. presented an experimental approach to accurately characterize the performance of a wet radome is discussed. The design, fabrication, and characterization of the propagation and scatter properties of seven-layer radome were presented. The circuital equivalent transmission line method was used to obtain the theoretical performance. Simulation performed in HFSS and measured results obtained in a customized RF chamber were used to validate the method proposed. The radome skin surface was implemented with non-hydrophobic, hydrophobic, and super-hydrophobic materials. Characterization of wet radome was evaluated as function of the radome geometry, position, and material. Good agreement was found between the theoretical, simulated, and measured results [9].

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